

FOOD TECHNOLOGY

BY

SAMUEL C. PRESCOTT, Sc.D.

*Dean of Science, and Head, Department of
Biology and Public Health*

AND

BERNARD E. PROCTOR, PH.D.

*Associate Professor of Food Technology and Industrial Biology,
Massachusetts Institute of Technology*

FIRST EDITION
SEVENTH IMPRESSION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK AND LONDON
1937

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THE MAPLE PRESS COMPANY, YORK, PA.

THIS BOOK

*is dedicated by the authors
to the Scientists, the Technologists, the Engineers
and the Industrial Leaders of broad vision
who have cooperated
in the application of scientific research
and have thus jointly made possible
the great advances which have characterized
the food industries of America*

PREFACE

From the dawn of history, the primal instinct of hunger has given man a compelling interest in the problems of securing and maintaining his food supply. First as a hunter and then as agriculturist and herdsman he acquired a simple but constantly enlarging knowledge of production and conservation. The growth of towns and cities involving larger needs and new difficulties in storage and transportation added to his problems and gradually transformed food production from an occupation to a business. Even then the danger of shortage and starvation faced the increasing populations, and primitive forms of food preservation were learned by experience. With the use of science the nature of various foods and the real significance of the principles of nutrition began to be known.

In the past five decades this knowledge has vastly increased, and especially since the turn of the present century there has been astounding development in food technology. Today the food industries, in which crude domestic methods have been transformed into highly organized and accurately controlled procedures for food manufacture and conservation, constitute one of the greatest and most important of our commercial enterprises, and one of the most interesting chapters in the history of specialized industries.

Food technology in the sense in which it is used in this work comprises the economic application of the laws and processes of biology, physics, chemistry, and engineering in the preparation and preservation of food products which are nutritionally of high quality, which are handled in a sanitary manner to prevent dangers from infection, and which may in many instances be kept for long periods or transported from regions of abundance to those of scarcity.

The published literature on food is voluminous, and many excellent books dealing with special phases of food production and preservation are available. As teachers who have for many years been specially concerned with the training of students who were to find places in the great food industries, we were unable, however, to find any single volume that could serve as the basis for a broad and constructive treatment of this important field of food technology. We have, therefore, brought together in this book a portion of the material used in our courses and we have attempted to emphasize the fundamental principles involved in the various methods of food manufacture and treatment rather than to give highly detailed accounts of the manipulations carried out in each particular case.

It is our hope that this volume may be of service to others than our own students, and that food manufacturers, nutritional directors, and those concerned with the official supervision and inspection of food supplies, as well as teachers and to some extent the general public, may find this volume of interest and value. Its production has been in part due to the result of many years of close association with food industries and the study of special types of problems that have arisen therein.

Many scientific journals, bulletins, and books on food have been consulted in preparing this work, and we wish to express our appreciation and gratitude to their authors. We have attempted to give special credit in the text where definite reference has been made. If any omissions have inevitably resulted, we should be glad to have them brought to our attention so that due credit may be given in any second printing.

We are indebted to many persons among whom are numerous friends, colleagues and former students, who have assisted directly or indirectly in making this text possible. To them we offer sincere appreciation for their services and kindness. Particular thanks are due Dr. A. W. Bitting for his cooperation in contributing the chapter on Canning, a subject on which he is a leading authority. Our deep indebtedness to our colleague, Dr. Cecil G. Dunn, is acknowledged for his great assistance in the compilation of material and statistical information and his splendid cooperation. Others to whom special recognition is due are Mr. Milton E. Parker and the late Mr. Joseph F. Phelan who have aided in the chapters on Milk and Dairy Products, and to Mr. J. M. Brown for helpful criticisms concerning the material on Sugar.

The especial courtesy of Dr. L. V. Burton, Editor of *Food Industries*, in placing at our disposal numerous flow charts and photographs which have been used in the text is gratefully acknowledged. Other organizations that have kindly cooperated in furnishing photographs include the McGraw-Hill Book Company, General Mills, Inc., Beech-Nut Packing Company, Cherry-Burrell Company, the United States Department of Agriculture, DeLaval Separator Company, Proctor and Schwartz, Inc., Milk Plant Monthly, General American-Pfaudler Company, Walker-Gordon Laboratory Company, and the Institute of American Poultry Industries. To each we extend our appreciation.

A companion volume considering the more detailed technological aspects of certain of the food industries for the use of more advanced students is contemplated in the not too distant future.

SAMUEL C. PRESCOTT.

BERNARD E. PROCTOR.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
April, 1937.

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FOOD TECHNOLOGY

CHAPTER I

INTRODUCTION

In an address given by Dr. Isaiah Bowman in 1935 before the American Association for the Advancement of Science, he said: "Over the greater part of the earth and for at least three-fourths of our two billion planetary population, the will to eat is the primary urge of the eternally hungry man."¹

It is easy to understand why from time immemorial the problem of food supply has occupied the mind of man since it springs from one of the most primal of man's instincts—hunger.² To satisfy the desire and the need of food the savage moved his habitation from hunting ground to hunting ground, depending on the meat, fish, or wild fruits and plants that might be found and later developed his primitive agriculture to guard against starvation. Such conditions may be found today in some of the more remote districts of the interior of Africa. Wars have been waged for food, and the instinct of self-preservation motivated the migrations of man as well as of lower creatures. At a much later period the production of food became a domestic industry engaging man's entire attention, and exchange of foods between neighboring people by barter constituted one of the early forms of trade.

From some such simple beginnings has arisen one of the most important, complex, and interesting of the social and economic problems of the present time—the world's food supply. Here is a problem not only personal and of immediate interest, but one the ramifications of which extend into many phases of national and international welfare, and which is intimately intermixed with the movements and numerical changes of populations, with the developments of science, and with that inexorable factor in the fate of civilizations, time.

In a superficial way, and from the standpoint of temporary necessities, our vision of the problem changes from time to time, depending on those elusive factors which we call world conditions. As we recall the meatless and wheatless days of two decades ago and compare them with the present days of agitation regarding farm relief, price fixing, control of surplus,

¹ BOWMAN, I., *Science*, **82**, 285, 1935.

² PRESCOTT, S. C., *Tech. Rev.*, **31**, No. 8, July, 1929.

and the other phases which enter so frequently into the lengthy discussions of the moment, we are brought to the conclusion that in a few brief years the barriers of a reputed impending food shortage have again been pushed back. The dire calamity predicted by Malthus in 1789 and to a lesser degree by Sir William Crookes a hundred years later, is still too far in the future to cause grave concern.

The scientist, however, thinks and works not merely for himself and the momentary need but, with the spirit of genuine altruism and human service, he must perforce envision a future which in the life of the individual may be remote but in the life of a nation or of a civilization is, in Scriptural phrase, but a day.

In order to foresee and estimate certain trends for the future we must review the story of food supply for the period of our national life. At the end of our Colonial Period, before the steamboat and the railroad had begun the contraction of the globe, man lived almost as he had lived for a thousand years. The industrial revolution had begun in England, and to some extent the change was felt in other parts of Europe, and even in the Colonies, but the arts of peace were still largely small-scale domestic arts. Invention had scarcely begun to modify the methods of labor; food supply was still largely a matter of individual effort and manual labor. It is not surprising that a man of the mental capacity of Benjamin Franklin should have found these conditions worthy of discussion and analysis, for to him belongs the credit of the first modern treatment of the relation of population to food supply. He was followed shortly by Hume and Wallace in Great Britain, and later by Townsend. In 1798 the thoughtful and pessimistic Malthus, noting the force of their arguments and the public disinterest in them, felt impelled to elaborate this doctrine, to call attention anew to the relation between population and subsistence, and to the dangers that were certain to follow the unrestricted increase in the numbers of mankind.

In 1800 the population of the known portion of the globe was, as nearly as can be estimated, about 750 millions, probably half of it in China, the home of real agriculture. Cities were relatively few and small. New York had but 60,000 inhabitants, although London was even at that time a city of a million souls. In America the population had hardly begun to stream into the great central valley but was almost exclusively on the Atlantic slope. The West was *terra incognita*. Canada, aside from the valley of the St. Lawrence, was a frozen blank; Australia, a mystery. Other parts of the globe, now of great significance from the standpoint of food supply, were then of no importance in this respect.

There are three principal areas of dense population, Southeastern Asia, Europe, and North America. According to Baker,¹ the first, South-

¹ BAKER, O. E., *Geog. Rev.*, July, 1928.

eastern Asia, including India, Siam, Indo-China, the East Indies, China, and Japan, contains about 900 million people, roughly one-half the population of the world. The second region, Europe, contains about 500 million, or about one-fourth the world's population. North America contains about 150 million, or one-twelfth of the population of the world.

The population of North America, which has three times the amount of arable land per person than Europe possesses, and six times that of Southeastern Asia, has for 100 years been increasing at a much more rapid rate than the other two regions. This population growth rate in North America has been due not only to natural increase but also because of a continued and often very large immigration, and the lower rates elsewhere are attributed in part to wars, famines, pestilence, and emigration.

Although the population increase in the United States has shown a growth unparalleled in history, the rate of increase for the past two decades has materially lessened, a fact due only in part to more restricted immigration. Europe's population increase has been numerically large but its rate of increase is at a lower level. Moreover, the standards of living have been raised, which generally signifies an increase in the per capita food consumption.

The conditions of a hundred years ago form a striking contrast to the conditions of today, with more than half of our people living in cities; with railroads, steamboats, automotive vehicles, and airplanes as rapid means of transportation; and with the telegraph, the telephone, and the wireless for instantaneous communications between distant points. These factors have vitally affected the equation of supply and demand. Furthermore, new areas have been opened up for cultivation, exploration, and migration.

As agriculture and food supply are primarily dependent on suitable land for crop production, the extent of arable soil on the earth's surface is of great importance. Large centers of population came into existence first in regions where there was land sufficient to produce crops which could sustain those increased populations. The intervening distance between the farmer and the consumer increased as transportation was developed and changed progressively from man power to pack animal, pack to wagon, wagon to railroad; rafts to boats, sailboats to steamboats. The size of the great metropolitan areas and density of populations have increased with a mounting dependence on transportation facilities for the food supplies. The staple foods may come from any country on the face of the globe, while perishable products may be hastened on their journeys by refrigerated express trains, fast boats, or even by airplanes.

In the general consideration of a world food problem our thoughts inevitably turn to the great staples which have for many years formed the

basis of the dietaries of civilized man. We may tabulate these staples into two relatively simple lists:

- | | |
|------------------------|---|
| Foods of plant origin | 1. The cereals: wheat, rice, corn, oats, rye, and barley
2. Sugar: from sugar cane, beets
3. Vegetables: potatoes, sweet potatoes, cassava, beans, peas
4. Fruits: such as banana and plantain |
| Foods of animal origin | 5. Meats; including beef, pork, mutton, poultry
6. Dairy products
7. Fish and seafoods |

Perhaps the one food universally considered as essential is cereal, but the importance of the other foods depends largely on the food habits of the individual. These habits have been developed in part through necessity, but national nutritional characteristics have grown up largely on the basis of the abundance of the foods most utilized or most easily obtained.

In certain respects all mankind is dependent on natural forces because with the exception of salt all our foods are of plant or animal origin. If one considers this situation further, it is apparent that all our food animals eventually owe their existence to plants. Even carnivorous animals obtain their food supply by preying on others which do depend on plant foods. The plants, in turn, are dependent on those comparatively simple chemical substances they obtain from the soil and the air, which are essential for their development. In addition to the chemical elements needed for their nutriment, sunshine or light irradiations provide the energy necessary for the synthetic processes which enable the plants to form sugars, starches, and other complex molecular combinations, including the proteins and fats, that make up the protoplasm of plant tissues. These fundamental changes could not progress, however, without the presence of chlorophyll which exerts a catalytic action on the necessary reactions.

Chlorophyll is the green coloring matter which is present in all green plants. It has been subject to much investigation, and studies of its chemical composition have shown that instead of one compound there are in reality two closely related chemical compounds concerned.¹ Without chlorophyll, and the synthesis by plants of foods in the form of carbohydrates, proteins, and fats, man would be unable to exist, as there would be no food supplies.

If man possessed the key of knowledge which unlocked the mysteries of nature completely, it might be desirable to gather together simple chemical compounds such as carbon dioxide and water which the plants use, incorporate the proper catalyst, and conduct the synthesis of sugars

¹ See SPOEHR, *Stanford Univ. Ann. Rev. Biochem.*, **2**, 453, 1933.
ARMSTRONG, *Chem. Ind.*, **52**, 809, 1933.

and starches on a gigantic scale in the presence of man-made sunlight or artificial light. If such were possible, the problems of man's food supply would indeed be simplified, but unfortunately this is not yet possible. Instead we are forced to depend for our foods on the vital synthetic laboratories of tiny plant cells, which in countless myriads, through the combined agency of sunlight, chlorophyll and their own vital activities, furnish the compounds that eventually serve in diverse forms as foods for man and provide sustenance for our food animals.

Natural selection or the survival of the fittest has been going on for countless centuries, long before man became interested in the cultivation of special crops for his own sustenance, and will doubtless continue to be a factor in this respect. It has been possible, however, to duplicate certain types of natural conditions and develop plants of tropical and subtropical requirements under glass for commercial crops, but this of course is but a minor part of our present-day agriculture.

Environmental conditions govern to a great extent not only the yields which may be expected from certain crops in a given area but dictate the types of crops which will grow at all in that area.¹ Much has been done in the past century in the way of introducing crops from other lands which will grow in our farm regions to better advantage than some which we formerly cultivated under less favorable conditions with lower efficiency.

The selection of plants, plant breeding, genetics, and its application to agriculture, soil chemistry, and physics, irrigation, the development of chemical fertilizers, the utilization of biochemistry in the study of chlorophyll and its function, the study of insects and insecticides, the science of bacteriology and its role in the study and prevention of plant and fungus diseases and numberless other aspects of science in relation to the growth of plants indicate only a few of the fronts on which man has worked to aid his growing field of knowledge concerning the procurement of his primary food supplies through the agency of living plants.

A closely allied field which requires and receives equally devoted attention is that of the development of animal food supplies through experimental research involving our food animals. Man is no longer able to depend on the fortunes of the hunt for his animal foods, although conservation of our natural game and fisheries resources is being studied and practiced. Our major food animals are selected, bred, fed, slaughtered, and transported under conditions which are constantly being improved by extensive research. Research helps to determine not only what foods should be fed to produce more meat per pound of food, but how and when it should be fed to produce the highest quality of beef,

¹ HANNAN, The Influence of Weather on Crops, 1900-1930, U. S. Dept. Agr., *Misc. Pub.* 118, 1931. A selected and annotated bibliography.

pork, poultry, milk, or eggs as the case may be. Our fisheries are subject to investigation and research to determine better policies concerning what might be termed our farming under the sea.

The handling of this great volume of food supplies and the making of food products therefrom is a problem of primary magnitude in the welfare of the nation and is of ultimate concern to every person dependent on these supplies for sustenance. The problems in this field of endeavor are numberless but are being gradually solved. The worlds of science and those of industry and finance have labored toward the ultimate goal of utilizing these food products of the soil and sun, with a minimum of loss due to spoilage or waste and a maximum of benefit to the consumer from the standpoint of economy, nutriment, health, and utility.

The biologist, chemist, physicist, engineer, and sanitarian all have made and are continuing to make contributions to such scientific endeavors. Some of the problems are being solved by unlocking the chambers of doubt or ignorance by the keys of exact scientific information, but there are many locks yet to be opened. Many technological methods of food handling according to older habits or customs have fallen by the wayside when weighed on the balance of strict scientific investigation. New food products have been developed and many new food sources tapped. Procedures and uses have been made available for the by-products associated with certain food materials. Much effort has been directed toward increasing our knowledge concerning the types of materials which may be harvested from the sea as well as conserving foods from this source which we now enjoy.

In the past three decades there has developed an increasing diversity in the diet of the average American, owing in part to the easier availability of foodstuffs of a wider variety. The perishable commodities of the past century which were available for only a brief period each year in locations close to the source of supply may now be obtained at almost any season whether produced nearby or at the ends of the earth. Many factors have combined to favor this widening of the horizons of food supplies and food products. Faster and more dependable transportation, improvements in refrigeration and other types of preservation, and increased knowledge in the technology of foods have each played an important part.

The changing habits of the present generation have had their influence on the production of foods also, because our urban inhabitants have come to prefer many of their foods in a prepared or partially prepared condition in order to lessen those duties in the home which were entailed in preparation. The modern breakfast table is likely to have its toast which is made from bread baked in large city bakeries; fruit juice from orchards a thousand or more miles away; breakfast foods prepared and packaged in the corn belt; coffee roasted and ground hundreds of miles away; cream or

milk from large dairies in distant counties or states; and sugar from the far-off beet fields or tropical plantations which has been refined and packaged in some city plant many hours away. Even the eggs may have arrived promptly, after a refrigerated ride in a transcontinental express freight, with the ability to demonstrate the pristine virtues of an egg hardly cool from the nest. It is apparent that many regions of our own country and lands beyond our borders are commonly used as sources of food supply, just as many processes, much equipment, and manifold technical services are required to furnish the products of the modern table in their desired form and quality.

Some 359 millions of acres in the United States were reported to have been harvested according to the census of 1930, which reflects the tremendous extent to which agriculture directly or indirectly assists in supplying our food needs, although coffee, tea, spices, and certain fruits are not raised in commercial quantities within our boundaries.¹ A vast army of workers is required, not only to plant, harvest, or raise the raw food materials, but also to transport, manufacture, merchandize, and deliver the products of these foods to the ultimate consumer. The harvested crop land in this country is estimated to constitute about 18.9 per cent of our land area, and in addition there are many more million acres available for pasturage purposes which serve as food supplies for food animals, as shown in Fig. 1.

It is less than three quarters of a century since the composition of food with reference to their components of protein, carbohydrates, and fat was at all clearly recognized, and the first real researches on foods were devoted to chemical studies on the composition of various food materials. A vast amount of work was bestowed on this aspect of food research in the last three decades of the nineteenth century and it is in general within that period that the great governmental laboratories of the leading European countries and in the United States were established for scientific control. While fundamental problems were in some degree considered, another aspect, namely, the examination of foods for adulterants, as a means of protecting the public against fraud as well as against possible harmful added substances, became one of the principal fields of food study, and with the improvement of the microscope this instrument added greatly to the facility of such investigations and to our knowledge of the structure of food materials.

Studies of most elaborate character on energy yield or fuel value soon followed knowledge of composition. The splendid work of Max Rubner and his disciples resulted in the widespread interest in calories and the

¹ Recent experiments by the Bureau of Plant Industry, U. S. Dept. Agr., have shown that coffee and cacao may be cultivated in southern Florida if the plants are given proper shelter. See O. F. Cook, *Science*, **83**, 56, 1936.

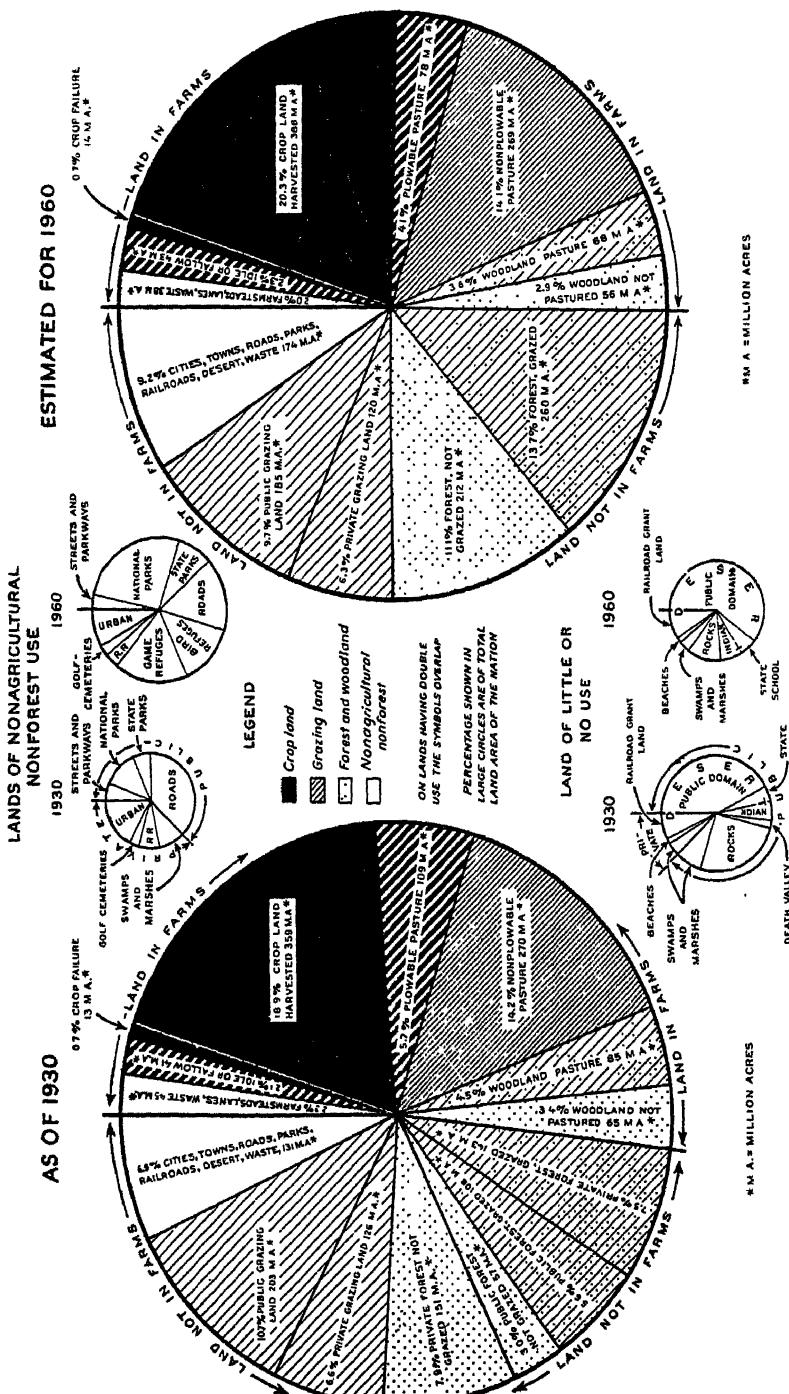


Fig. 1.—Major uses of land in the United States. (*U. S. Department of Agriculture.*)

energy values of foods. Rubner showed clearly how foods serve as fuels for the human machine. In this country epoch-making investigations were carried out by Professor Lusk and others, and the study of the food needs for workers in various kinds of occupations, such as those requiring great muscular effort on the one hand and the less exacting sedentary pursuits on the other, were carefully studied and evaluated. Thus was created an interest in calorific values and food requirements as expressed in diets of varying complexity. This interest had its peak about a generation ago, but it is still potent enough in its appeal to popular imagination to cause certain purveyors of food to tabulate calorific values on the menus which they provide their customers. It was soon found, however, that not all the recognized facts of nutrition could be explained solely on the basis of calorific value, for large numbers of cases were evident in which the total food intake was ample to supply the food requirements and yet the consumers were not necessarily well nourished nor did they continue in good health. Therefore further research was necessary to explain these matters and to find the causes of the deficient metabolism. One of the outcomes of this long and patient study was the discovery by Osborne and Mendel of the different essential types of amino acids derived from protein food which, when assimilated, may become the building blocks by which the structures of the body are continuously reconstructed and maintained, while at the same time the worn out material is being eliminated in the body wastes. Regardless of the number of calories which might be obtained by actual combustion, if, in the digestive cleavages of a protein food, the requisite types of amino acids are not all produced, the body does not obtain the full complement of structural materials. Furthermore, it became recognized that certain portions of the food, such as the fats and sugars and starches, were consumed largely to yield energy in the form of heat, while the proteins, on the other hand, supplied the material for structure and repair of the tissues. Thus the concept of a balanced ration was the direct result of research.

From the practical or commercial standpoint another line of food research was clearly recognized some forty years ago. From simple beginnings far in the past, great advances had already been made in the technique of food preservation by canning, drying, preserving, and even in refrigeration. There had also been enormous and unexplainable losses, for manufacturers did not know the underlying fundamental sciences. The problems of food spoilage and of maintenance of foods in good condition therefore became of vast importance, and especially so with urban development, higher living standards, and growing industrial life. Here was an economic problem of prime significance, and the attack thereon opened up vast fields of food research which has been of immense commercial significance and greatly enriched our knowledge. Without

keeping in mind the advances of science it is difficult to visualize the methods or understand the opinions and attitudes of 50 years ago. Through years of hard experience and empirical trial and error, a good but inexact practical knowledge of the effect of cold and heat, of the use of spices and sugar as preservatives, and of drying, pickling, and smoking, had come down from a remote past. The reasons were unknown—why could the Indians in the hot dry Southwest preserve buffalo meat by simply hanging the strips of it in the sun? Why could the colonial housewife preserve blueberries by use of cloves and other spices, or wild strawberries with sugar? Why did corned beef or salt pork keep for months until used? It remained for the real scientific research in the last few decades to explain why these processes were possible and to put them on a successful basis. Thus, while the rule of thumb experiments of Appert in France and of Saddington in England early in the nineteenth century laid the foundations of the canning industry, it was not until after bacteria were known as living things, and the application of the more exact knowledge of microbe life had begun to be elucidated by Pasteur, in the sixties of the last century, that the fundamental causes of food decomposition even began to be made clear. It was also Pasteur who, in his long and scrupulously careful studies on the causes of deterioration in wines found that by use of a temperature of 158°F. maintained for 15 to 30 min. he could prevent wines from becoming sour, turbid, and useless, while if not heated they would have been a total loss. No doubt the practice of scalding certain fluids in order to lengthen their keeping time had been employed long before his era. But it was his research that gave this process definite characteristics and transformed a haphazard and mysterious action into the application of a fundamental principle based on definite data. Thus pasteurization was evolved. The importance of this piece of careful observation and experiment, viewed in the light of its subsequent application to milk supply, is of untold magnitude, for it has been one of the greatest factors in the conquest of disease and the promotion of public health.

Not until bacteriology was studied in its specific relation to the different branches of the food industry itself could their processes become established on a commercially and scientifically sound basis. In most food industries this did not take place until the nineties or later.

Hand in hand with the progress of bacteriology and its applications in the food industries has come increased usage of chemistry and other sciences which has resulted in improvements of methods and new food products. Engineering has made possible the handling of food products more efficiently and eliminated many of the inefficiencies of small-scale food production. The use of by-products in larger food organizations such as the packing houses is a notable example in this respect. Refrig-

eration by mechanical means has made possible the utilization of many products which would otherwise be unknown because of the barriers of time or distance and has given rise to the new quick-freezing industry.

The chemical engineer has opened wide vistas in the use of edible oils by the conversion of such substances to solid fats by hydrogenation, enabling usage of the plant products of the tropics as sources of materials for the tables of cooler countries. The development of carbon dioxide which Priestley described a hundred years ago has only come into its own within the past decade with the production of solid carbon dioxide. This product has many uses as a refrigerant and has become a factor in refrigerated transportation because it has the additional ability of restraining spoilage due to some types of microorganisms, thereby extending the storage periods of certain foods.

The development of electricity is intimately related with all food production. Fertilizers for our food plants may now be obtained by electrical methods, using nitrogen from the air instead of importing nitrates from Chile or equally distant deposits. The progress of electrical engineering has been intimately connected with food production in many ways. Electricity turns the wheels of our food factories, lights our buildings, may propel our trains and trucks. It is used to irradiate hens for higher egg production, and ultraviolet lamps may be used to build up the vitamin D content of milk. Artificial light may be used to stimulate the growth of plants in scientific horticulture, and certain wavelengths, either from the sun or from artificial lamps, can increase or shorten the latent period of certain seeds at the will of the planter.

It would be impossible and likewise impractical to attempt an evaluation of all the various scientific factors concerned in food technology and its development, but in the modern food industries a combination of the efforts of thousands of workers over many years has made possible the present status of processes now used. Improvements are being made daily, certain mechanisms and methods continually becoming obsolete in the light of changing conditions. The modern methods of today will be discarded tomorrow when more is learned concerning foods and the way in which they may be made better, more appealing to the public, safer, more efficiently, or more cheaply as the case may be.

The economics of food supply and food products present many broad fields for scientific and technologic research and application. The most efficient choice and utilization of land for the raising of particular food crops, the conservation for food purposes of land which is now wasted, proper crop rotation and fertilization, seed selection, plant and animal breeding, control of disease in crops and animals, prevention of spoilage, control of insect depredations, all afford problems worthy of greater attention.

The storage, transportation, refrigeration, and preservation of foods in their natural form and food products made therefrom, the elimination of deleterious changes due to enzymes or microorganisms, the more efficient utilization of by-products, the proper utilization of foods in the dietary—each presents challenges to science and the student of foods who has a scientific training.¹

The individual who makes his decision to enter the food industries and food research will never lack for problems as they are manifold. New difficulties and means by which they may be surmounted are constantly appearing. In some instances the solution may be found in the basic methods or knowledge of another food industry handling different materials yet having the same fundamental problems. Thus a broad insight in varying technologic processes often serves as a useful foundation for more specialized applications in specific fields. From this standpoint, food technology in its varying aspects affords ample opportunities for the study, research, and development of food processes, techniques, and products. Such endeavors may at times require the specialized training of the well-grounded biologist, chemist, engineer, physicist, or other scientist. Many times the endeavors are more likely to be solved by persons who have the viewpoint obtained from an intimate knowledge of several sciences and it is the person with the ability to bring into play a sound knowledge of the interrelations of the knowledge of these various fields who is likely to be the worth-while food technologist of the future.

The logical procedure for a start in this direction, however, is to become familiar with the manner in which foods are harvested, transported, manufactured and prepared for use, why certain processes are utilized and how the methods are practiced; in other words, by familiarizing oneself with the food technology of the present day.

¹ LINCOLN, A. T., *Science*, **40**, 463, 1934.

CHAPTER II

WHEAT AND MILLING

WHEAT

Wheat is one of man's most ancient and highly respected food materials. There is reason to believe that prehistoric man was familiar with the virtues of wheat and similar grains as sources of food. That there were numerous varieties of wheat was recorded by one of the students of Plato in about 300 B.C. At this early period many of the varieties were known by names indicating the country of origin although distinct differences in physical characteristics such as size, shape and color were apparent. The generic name *Triticum* has been used for wheat more than two thousand years and may have its derivation in the Latin verb "tritare" meaning to thresh or to grind, as the name may have once related to all grains handled in this manner.

Many of the descriptions of wheat written in the period of the Roman Empire bear close resemblance to some varieties still in existence. Its climatic characteristics are well adapted to the Holy Lands and within the present century a variety of wild emmer, a reputed ancestor of our present cultivated wheat, was found growing on Mt. Hermon in Palestine. The many Biblical references to wheat and bread clearly indicate the importance of this grain and its cultivation to the people in those regions in that era. In many parts of the world wheat is held in equally high esteem today and constitutes a very significant portion of the dietary.

The wheat plant is capable of growing in regions of relatively low rainfall and likewise of surviving rather wide extremes of temperature. The period in the life cycle of the plant when the rain does occur is of particular importance and should be preferably during the earlier part of its development. Good crops are facilitated by a period of maturation consisting of sunny warm weather and the absence of rain. Such conditions favor the development of seed or kernel rather than straw and are inimical to the cereal rusts, fungus diseases which raise havoc in wet weather.

Those conditions favorable to growth are met in many widely separated parts of the world and range from the tropics to Norway at a 64° N. latitude, from sea level to some altitudes of 8,000 ft. or over, and from irrigated desert areas to the regions of high seasonal rainfall which are fortunately followed by dry warm weather.

Smith¹ indicates eight important wheat-growing regions which are as follows: (1) The plains of southern Russia and the Danube valley, (2) the country bordering the Mediterranean, (3) Northwestern Europe, (4) the central plains of the United States and Canada, (5) Columbia Basin of the United States, (6) Northwestern India, (7) Eastern Argentina, and (8) Southern Australia.

The cultivation of wheat as a food crop has apparently extended over countless centuries. The exact geographical origin of this most important food plant is not certain, although it has been cited as growing in China as early as 3000 b.c. The Old Testament refers to wheat and it appears evident that this plant was also an important food crop of the ancient Egyptians. Wheat is also said to have been found in the settlements of the early Swiss lake dwellers.

The importance of wheat has not diminished to any extent, for man still holds in highest esteem the bread which may be made from this widely grown plant. In this country wheat was grown on about 60 million acres of our farm lands from 1926-1930, and the crop during this period averaged over 850 million bushels annually. It has been estimated that nearly one-third of the farmers in the United States are engaged in growing wheat, and a considerable number of these farmers are entirely dependent on this crop for their livelihood. Exports of wheat have constituted a valuable portion of our international trade and for two decades, previous to 1931, more than 12 per cent of our total annual wheat production was exported. Both acreage and exports have been somewhat reduced since that time.

The production of wheat in the United States has been closely allied with the development of the country, as the westward movement of wheat production was coincidental with the development of roads, waterways and railroads which were needed to transport the wheat from the farm to the large cities and ports of the seaboard.

In Colonial days wheat was grown on most farms, harvested with a sickle and subsequently threshed by hand with a flail, or by driving animals in a circular path through the sheaves to separate the kernels. The same primitive methods existed into the early part of the past century when the cradle was invented, which enabled the scythe-cut wheat to be deposited in rows. Cyrus McCormick invented the reaper in 1851, thereby making it possible to cut the mature wheat and drop it in bundles ready to be tied. This reaper led to other mechanical improvements which cut labor requirements and made it possible to produce wheat in larger acreage with the same man power. The thresher, which separated grain from the straw, was eventually united with the harvester. The modern "combine," harvester and thresher combined,

¹ SMITH, J. R., *The World's Food Resources*, 1919.

may cut and thresh all the wheat on a hundred or more acres a day. The primitive horse-drawn reaper of McCormick's day has given way to the tractor combine units which require relatively few men and need no horses which must be fed each day of the year. In 1923 almost 20,000 combines were sold in the United States.

Statistical data of wheat production in various countries since the World War (Table 1) indicate that Russia, United States, Canada, India, France, Italy, Argentina, Germany, Australia, and Spain are the leading wheat producers. The supremacy formerly held by this country in wheat production appears to have been won by Russia which reported a production in 1933-1934 of over a billion bushels. Since the bumper U. S. crop of 1931-1932 which amounted to over 900 million bushels, the

TABLE 1.—WHEAT PRODUCTION BY COUNTRIES (1921-1935)*
(1,000 Bu.)

Country	Average 1921-1922 to 1925-1926	1931-1932	1932-1933	1933-1934	1934-1935
North America:					
Canada.....	366,483	321,325	443,061	269,729	275,252
United States.....	786,866	932,221	745,788	528,975	496,469
Mexico.....	10,226	16,226	9,658	12,122	10,104
Europe:					
U. S. S. R.....	457,857	753,238	744,052	1,018,893	
France.....	290,774	264,117	333,524	362,830	332,000
Italy.....	198,307	244,415	276,922	297,987	232,687
Spain.....	142,420	134,427	184,207	138,235	180,042
Germany.....	98,714	155,546	183,830	205,920	166,541
Rumania.....	89,570	135,300	55,537	119,072	77,315
Jugoslavia.....	58,753	98,789	53,444	96,584	68,328
Hungary.....	59,678	72,550	64,463	96,356	61,447
Poland.....	48,708	83,220	49,472	79,883	63,468
Africa:					
Morocco.....	21,758	29,783	27,970	28,902	31,232
Algeria.....	26,716	25,649	29,237	31,998	39,738
Tunis.....	7,892	13,963	17,453	9,186	15,800
Egypt.....	36,806	46,073	52,586	39,951	37,277
Asia:					
Turkey.....	104,946	71,135	99,636	88,546
India.....	336,271	347,424	336,896	352,763	349,365
Japanese Empire.....	37,171	39,931	39,936	49,263	54,420
Southern Hemisphere:					
Chile.....	25,761	21,187	26,114	35,307	
Argentina.....	208,388	219,696	240,889	286,120	252,059
Australia.....	128,520	190,612	213,927	175,370	137,000

* Yearbook of Agriculture, 1935.

production of wheat has decreased markedly (over 40 per cent in some years), owing in part to the most severe drought ever experienced in our Midwest and partly to the economic depression of the same period. The total world production is larger than that for prewar years despite unfavorable climatic and crop conditions in some regions. The assumption that no real world shortage of wheat is likely to occur for such reasons because of the widely separated regions of cultivation seems well founded.

For many years wheat was an important export crop of the United States and from one-fifth to one-third of all the wheat raised was shipped overseas for consumption in other countries. During the past decade there has been a decided decrease in our wheat exports, particularly in the past two years when less than 5 per cent was exported. Economic conditions, tariff changes, surplus crops from other large producing countries and our own reduced crops have all played a part in this decrease. The extreme changes in price which wheat has undergone in this country since the Civil War and the low prices during our recent depression years offer interesting comparisons (Table 2). In 1870

TABLE 2.—YIELD, PRICE, AND EXPORTS OF WHEAT PRODUCED IN THE UNITED STATES (1876–1934)*

Year	Average yield per acre, bu.	Production, 1,000 bu.	Price per bushel at Chicago, cts.	Per cent exported
1870	12.1	254,429	115	20.5
1880	13.2	502,257	99	37.5
1890	12.2	449,042	97	24.3
1900	12.2	599,315	72	36.8
1910	13.7	625,476	100	11.2
1920	13.5	843,277	216	37.1
1924	16.0	840,091	139	30.3
1925	12.8	669,142	161	13.8
1926	14.7	833,544	140	24.7
1927	14.7	874,733	138	21.8
1928	15.4	912,961	117	15.6
1929	13.0	822,180	130	17.1
1930	14.2	889,702	84	12.6
1931	16.3	932,221	53	13.3
1932	13.1	745,788	53	4.3
1933	11.0	528,975	94	4.8
1934	11.8	496,469		

* Yearbook of Agriculture, 1935.

wheat sold for an average of \$1.15 a bushel, in 1920 for \$2.16 and in 1931 and 1932, for 53 cents, with sometimes few buyers. The average yield per acre in the United States was approximately 5 bushels less in

1933 than in 1931 when over 16 bushels were produced, which gives evidence of the tremendous damage done by the drought.

Table 3 lists the more important wheat-producing states and their production in recent years in the order of their relative standing. The averages for 1927-1931 are fairly representative of the pre-drought period, with Kansas and North Dakota outstanding, followed by Nebraska, Oklahoma, Montana, Washington, Texas, and South Dakota. The decreases in yields of some of these states in 1933 and 1934 show the marked changes which climatic and economic upsets may exert on agriculture. Thousands of acres of land once used for wheat have been permanently eliminated as far as wheat production is concerned but in spite of these losses it appears that with normal weather conditions no wheat imports are necessary to meet the requirement of our nation.

TABLE 3.—WHEAT PRODUCTION IN THE UNITED STATES BY LEADING STATES*
(1,000 bu.)

State	Aver- age 1927- 1931	State	1933	State	1934
Kansas.....	176,235	North Dakota.....	72,115	Kansas.....	79,700
North Dakota.....	107,581	Kansas.....	57,504	Oklahoma.....	37,348
Nebraska.....	65,418	Washington.....	43,044	Washington.....	37,346
Oklahoma.....	52,641	Ohio.....	34,812	Ohio.....	33,401
Montana.....	50,388	Oklahoma.....	31,549	Indiana.....	32,151
Washington.....	45,345	Nebraska.....	29,206	Illinois.....	29,495
Texas.....	39,653	Illinois.....	27,418	Montana.....	28,174
South Dakota.....	36,466	Montana.....	26,480	Texas.....	25,749
Illinois.....	34,372	Indiana.....	22,905	Missouri.....	21,281
Ohio.....	29,673	Oregon.....	17,608	North Dakota.....	21,196
Indiana.....	27,626	Idaho.....	17,235	Idaho.....	18,696
Idaho.....	27,343	Missouri.....	16,989	Nebraska.....	15,838
Oregon.....	22,701	Minnesota.....	16,665	Pennsylvania.....	14,759
Minnesota.....	20,974	Pennsylvania.....	15,783	Oregon.....	12,944
Missouri.....	20,374	Texas.....	14,008	Minnesota.....	12,534

* Yearbook of Agriculture, 1935.

Biological Description and Classification.

Wheat belongs to the grass family, Poaceae (Gramineae), and to the tribe Hordeae, in which the one- to eight-flowered spikelets are sessile and alternate on opposite sides of the rachis, forming a true spike. Wheat is located in the sub-tribe Triticeae and in the genus *Triticum*, where the solitary two- to many-flowered spikelets are placed sidewise against the curved channelled joints of the rachis.

There are two sections of the genus *Triticum*, one including the old genus *Aegilops*, in which the glumes are flat or rounded on the back, and the other including *Sitopurus*, in which the glumes are sharply keeled. All cultivated forms are found in the latter.

Wheat is characterized as a mid-tall annual grass with flat blades and a terminal spike. The spikelets are solitary, one- to five-flowered, sessile, arranged alternately on the nodes of a zigzag, channeled, articulate rachis; the rachilla of the spikelets disarticulating above the glumes and between the florets, or continuous; the glumes keeled, rigid, three- to several-nerved, obtuse, acute, or acuminate; the lemmas keeled or rounded on the back, many-nerved, ending in a single tooth or awn.¹

There are almost infinite varieties of wheat which have been named and described. As early as 55 A.D., Columella described three types of *Triticum* and four types of bearded wheat, spelt, or emmer. Linnaeus, in 1753, established the first scientific classification of wheat, since which time numerous changes and additions by workers in every country resulted in rather confused nomenclature. There are now 230 standard varieties and 43 improved varieties registered in the United States which have been established through the studies of Clark and others of the U. S. Department of Agriculture.²

Numerous taxonomic characters are essential for the purposes of identification and description of wheat species and varieties, including the following: habit of growth, time of heading and ripening, height, stem color and strength, leaf character, spike characters, glume characters, awn characters and kernel characters. The major kernel characters are color, length and texture, although differences of the germ, crease, cheeks, and brush are also taken into consideration. In recent classifications of wheat species, chromosome numbers have also been used as a basis of classification.

The following key has been proposed by Clark and Bayles to the species of subspecies of wheat.¹

- 1a. Chromosome number 21 in haploid division.
- 2a. Terminal spikelets fertile; palea remaining entire at maturity; spikelets with 2 to 5 fertile florets.
- 3a. Glumes shorter than the lemmas, firm: palea as long as the lemmas. (*Triticum sativum* Lam.)
- 4a. Rachis tenacious; kernels separating from the chaff when threshed.
- 5a. Glumes distinctly keeled only in the upper half; lemmas awnless or awns less than 10 cm. long; straw hollow.

¹ CLARK, J. A., and B. B. BAYLES, U. S. Dept. Agr. Tech. Bull. 459, 1935.

² For a detailed and complete discussion of wheat varieties see CLARK, J. A., J. H. MARTIN, and C. R. BALL, U. S. Dept. Agr. Bull. 1074, 1922.

- 6a. Spikes usually long, dense to lax, somewhat dorsally compressed. (*T. aestivum* L., *T. vulgare* Vill.) .. COMMON WHEAT
- 6b. Spikes short, dense, laterally compressed. (*T. compactum* Host)..... CLUB WHEAT
- 4b. Rachis fragile; kernels enclosed in glumes when threshed.
- 5b. Spikes lax, narrow; pedicel long, wide, attached to face of spikelet below; shoulders wide, square. (*T. spelta* L.)..... SPELT
- 1b. Chromosome number 14 in haploid division.
- 2a. Terminal spikelets fertile; palea remaining entire at maturity; spikelets with 2 to 5 fertile florets.
- 3a. Glumes shorter than the lemmas, firm; palea as long as the lemmas. (*T. sativum* Lam.)
- 4a. Rachis tenacious; kernels separating from the chaff when threshed.
- 5b. Glumes sharply keeled at the base; lemmas usually awned; awns 10 to 20 cm. long; straw usually solid.
- 6a. Glumes and kernels short; kernels ovate, with truncate tips. (*T. turgidum* L.)..... POULARD WHEAT
- 6b. Glumes and kernels longer; kernels usually elliptical. (*T. durum* Desf.)..... DURUM WHEAT
- 4b. Rachis fragile; kernels enclosed in glumes when threshed.
- 5a. Spikes dense, laterally compressed; pedicel short, slender, usually attached to base of spikelet; shoulders wanting to narrow, usually oblique. (*T. dicoccum* Schrank)..... EMMER
- 3b. Glumes as long as or longer than the lemmas, papery, lanceolate; palea of lower flowers half as long as their lemmas. (*T. polonicum* L.)..... POLISH WHEAT
- 1c. Chromosome number 7 in haploid division.
- 2b. Terminal spikelets sterile, often scarcely visible; palea falling into 2 parts at maturity; spikelets usually with only 1 fertile floret.
- 3a. (*T. monococcum* L.) .. EINKORN

Of the species or subspecies listed above, common wheat (*Triticum aestivum* Linnaeus, or *Triticum vulgare* Villars) is the most widely grown and utilized and comprises 201 of the United States varieties. Its popularity is based on the reputation of these varieties as raw materials for flour capable of making high quality bread. Club wheat is not so desirable for bread flour but is used for biscuit and pastry flour. Durum wheat is used to a considerable extent for the manufacture of macaroni and spaghetti. The others are of relatively minor importance from the standpoint of both production and use in this country.

Official Grain Standards.—The following definition of wheat is used for the purpose of official grain standards of the United States:

Wheat shall be any grain which, before the removal of dockage, consists of 50 per cent or more of wheat and not more than 10 per cent of other grains for which standards have been established under the provisions of the United States

Grain Standards Act, and which, after the removal of dockage, contains not more than 50 per cent of broken kernels of grain of any size. The term wheat in these standards shall not include emmer, spelt, einkorn, Polish wheat, and poulard wheat.

From an official standpoint wheat is separated into seven classes which are very carefully defined and used as a basis for commercial transactions. They are as follows:

Class I. Hard Red Spring Wheat.

- Subclass (A) Dark Northern Spring.
- (B) Northern Spring.
- (C) Red Spring.

Class II. Durum Wheat.

- Subclass (A) Hard Amber Durum.
- (B) Amber Durum.
- (C) Durum.

Class III. Red Durum.

Class IV. Hard Red Winter Wheat.

- Subclass (A) Dark Winter.
- (B) Hard Winter.
- (C) Yellow Hard Winter.

Class V. Soft Red Winter Wheat.

- Subclass (A) Red Winter.
- (B) Western Red.

Class VI. White Wheat.

- Subclass (A) Hard White.
- (B) Soft White.
- (C) White Club.
- (D) Western White.

Class VII. Mixed Wheat.

The foregoing definitions indicate that one basis of differentiation used in wheat depends on its cultivation, namely, whether it is winter wheat or spring wheat. Winter wheat is planted in the fall, stays in the ground all winter and is harvested early in the following summer. Spring wheat is planted as early as possible when the ground can be worked and is harvested during the latter part of the summer.

In 1929 it was estimated that 43.5 per cent of the wheat acreage of the United States was planted with hard red winter wheat, 22 per cent with hard red spring wheat, 17.7 per cent with soft red winter wheat, 9.4 per cent with Durum, and 7.4 per cent with white wheat.¹

Hard red winter wheat is grown principally in the south central and north central states and is the most important class raised in Iowa, Nebraska, Kansas, Oklahoma, Texas, Colorado, New Mexico, and Utah. Three most important varieties are Turkey, Black Hull, and Kanred.

¹ CLARK J. A., and K. S. QUISENBERRY, U. S. Dept. Agr. Circ. 283, 1933.